Report of the MEPAG Mars Human Precursor Science Steering Group Technology Demonstration and Infrastructure Emplacement (TI) Sub-Group

Hinners, N.W. (Consultant), Braun, R.D. (Georgia Tech),
Joosten, K.B. (JSC), Kohlhase, C.E. (Consultant), and Powell, R.W. (LaRC)

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Report Clearance

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MHP SSG Charter

The Mars Human Precursor Science Steering Group was chartered on behalf of MEPAG to:

1. Identify the activities that should be performed by human precursor robotic missions for the purpose of reducing cost and/or risk of human exploration missions

2. For measurement-related activities (Measurement Sub-Group – see *An Analysis of the Precursor Measurements of Mars Needed to Reduce the Risk of the First Human Mission to Mars* at *http://mepag.jpl.nasa.gov/reports/index.html*):

   a) Identify and justify new measurements that can be acquired by robotic missions to Mars that would contribute to the overall cost or risk reduction objective. Where possible, include precision and accuracy.

   b) Establish preferred / required sequential relationships for measurement sets, etc.

   c) Suggest the number of distinct sites needed for each of the measurements in order to achieve cost and risk reduction as well as the necessary characteristics of the different sites.

   d) Prioritize the measurement options.

MHP SSG Charter, Cont.

3. For technology demonstrations and infrastructure (TI Sub-Group, this report):
    a) Identify technology flight demonstrations needing to be performed on Mars to reduce risk to human flight systems
    b) Prioritize technology demonstrations and infrastructure and suggest preferred / required sequential relationships

Technology & Infrastructure Sub-Group Membership

Hinners	**Noel**		**Consultant**		**Co-Chair**
Braun	**Bobby**		**Georgia Tech**		**Co-Chair**
Houghton	Martin		GSFC		Transit
Joosten	**Kent**	**Transit Sub-Team**	**JSC**		**Chair, Transit**
Pearson	Don		JSC		Transit
Rush	James		JSC		Transit
Rush	John		NASA Hq		Transit
Tyburski	Tim		GRC		Transit
Arnold	Jim		Univ. Calif.	**A (Ex-NASA)**	Atm.
Braun	Bobby		Georgia Tech	**A (Ex-NASA)**	Atm.
Graves	Claude		JSC		Atm.
Powell	**Richard**	**Atmosphere Sub-Team**	**LaRC**		**Chair, Atm.**
Stephenson	David		MSFC		Atm.
Tolson	Robert		NIA		Atm.
Venkatapathy	Ethiraj		ARC		Atm.
Whetsel	Charles		JPL		Atm.
Akin	David		Univ. Md	**A**	Surface
Clark	Ben		Lockheed Martin	**I**	Surface
Drummond	Mark		ARC		Surface
Edwards	Chad		JPL		Surface
Fincannon	James		GRC		Surface
Gershman	Robert	**Surface Sub-Team**	JPL		Surface
Hoffman	Steve		SAIC	**I**	Surface
Kohlhase	**Charley**		**JPL**		**Chair, Surface**
McCann	Rob		ARC		Surface
Rapp	Don		JPL		Surface
Sanders	Gerry		JSC		Surface

Preparing for Human Exploration
The Context

A Full Program of Preparing for a Human Mission(s) to Mars Needs to Consider the Following Components:

The full job

- Flight Missions to Mars
  - –Measurements of the Martian Environment.
  - –Technology Demos/Infrastructure Emplacement
- Missions to the Moon
- Laboratory, Field, and Flight test program on Earth
- Flight Missions in/to Earth Orbit

F O C U S

The TI Sub-Group Also Identified Demonstrations That Should Be Done on Earth, in Earth Orbit or on the Moon

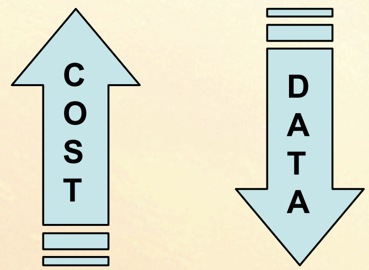
General TI Sub-Group Study Programmatic Assumptions

ASSUME:

- A series of Mars robotic precursor missions prior to human exploration. It is not yet known whether launches in every opportunity are justified, so this should not be assumed.
- The first dedicated robotic precursor mission is scheduled for flight in the 2011 launch opportunity, and that the first human mission is scheduled for approximately 2030.
- A series of robotic precursor missions will be designed to reduce risk/cost in the first human mission. Assume that there will be subsequent missions which may build upon the first.
- A separate sequence of Mars missions, with a primary objective of robotic scientific exploration, will be carried out in addition to the human precursor sequence. Assume that the infrastructure associated with the science missions (e.g. the telecommunications infrastructure) is available for use by the human precursor missions.
- The 2030 mission and all of the precursor missions are funded by NASA without contributions from international partners.

TI Prioritization Criteria

- The Technology is **Likely Required** to Significantly Reduce Risk and/or Cost of Human Exploration to an Acceptable (Affordable?) Level
- Venue: The Importance that the Technology Demonstration be **Best** Performed (**Technical Benefit vs Cost**) on a Mars Flight
    1. **At or In Transit to Mars**
    2. On the Moon
    3. In Earth Orbit
    4. On Earth



The Increasing Cost and Decreasing Data Acquisition Opportunities Favor non-Mars Venues

- Evaluate All Venues to Assure Completeness & Assessment of Cost/Benefit
- Priorities Separately Evaluated Within Time Phases
    - **Early**: Influence Major Architecture Decisions (pre-Phase A) [2011 – 2016]
    - **Mid**: Influence Mission & Flight Systems Design [2018 – 2022]
    - **Late**: Operations Preparation Phase [2024 – 2028]
- Four Priority Categories: VH, H, M, L at Sub-Team Level

TI Working Approach

- Initiated Work at MHP SSG Workshop held in Monrovia, CA August 3 – 4, 2004
  - The TI Sub-Group Was Divided Into Three Mission Phase Sub-Teams: Each Has Unique and Separable Functions and Thus Requirements
    - Transit [T]: To and From Mars
    - Atmosphere [A]: Mars Entry, Descent and Landing, Ascent
    - Surface [S]
- Mission Phase Sub-Teams Worked Independently from Aug. 5 to Sept. 16, 2004 Primarily by E-mail and Telecons
  - Template and Refined Groundrules Defined and Distributed
  - Common Prioritization Criteria Defined and Distributed
  - All Work Was Captured in Template Form
    - Facilitated Common Baseline for Prioritization
    - Forced a Focus on Objective Criteria
- A TI Integration Meeting Was Held September 16, 2004 at JPL
  - Sub-Team Input Ranked in Priority Groups 1 – 3 (No Sub-Prioritization)
  - Only <u>Highest Priority</u> “at Mars” Items are Included in MEPAG IVB Goals
    - There Are Many Additional Items Captured in Templates
- The TI Sub-Group Priorities Were Provided as Input to Testbed Mission Architecture Studies by Frank Jordan, JPL

Evaluation Template

- Topic
- Mission Phase Identifier: Transit, Atmosphere or Surface
- Requirement Statement
- Rationale
  - Source of the Requirement with Description of Risk or Cost Reduction or Infrastructure Implication
- TRL Level of Development/Technology
  - TRL 1 – 9 Scale
- Priority Ranking with Justification
  - Very High, High, Medium, Low
- Where, with Justification
  - At or In Transit to Mars, Moon, Earth Orbit, Earth
- When, with Justification
  - Early (2011-2016), Mid (2018-2022), Late (2024-2028), Anytime
- Clarifying Comments

A Systems Level Technology Template:70 deg sphere-cone aerocapture

Requirement

Demonstrate a representative end-to-end aerocapture system at Mars using the Viking-type aeroshell design. System is comprised of approach navigation, hypersonic atmospheric entry and exit, periapsis raise maneuver, and final orbit adjust. The target orbit would be that representative for a human mission to Mars. The atmospheric flight portion and periapsis raise maneuver would be autonomous. If funding allows, this could be followed by an hypersonic entry to prove viability of multiple-use TPS (See component technologies), thermal management, etc.
Additional funding would allow a pinpoint landing demonstration. (See component technologies)

TRL (aerocapture)
5

Rationale

The objective of this demonstration is to validate aerocapture as a viable capability for t[illegible]xploration Initiative. This capability provides significant performance advantages and is required for the architectures o[illegible]roposed by the exploration initiative. NASA system studies, and CNES project studies have all shown that [illegible]re significantly reduces the entry mass, and thus reduces the launch mass requirements, the infrastructure r[illegible]nd the total cost. However, this capability has never been demonstrated in-flight. The NASA Aeroassist Flight Exp[illegible](1980's), the original 2001 NASA Mars Orbiter mission, and the CNES 2005 orbiter mission all were to use aerocap[illegible]f these projects were canceled before launch, but none had uncovered any technical issue that needed to be r[illegible]efore aerocapture could be used. Because the objective of the Mars Precursors is to validate the technologi[illegible]ed for human exploration, aerocapture must be performed at Mars to capture the aerothermodynamic a[illegible]heric characteristics, the proper dynamics.

EXAMPLE COMPLETED TEMPLATE

Assessment

VH — Priority & Justification	MR — Where & Justifi[illegible]	E — When & Justification	Comments
This is a cornerstone of the exploration initiative and this fundamental capability must be demonstrated early to **validate the exploration initiative architecture.**	System de[illegible]Mars approach nav, spacec[illegible]ynamics [as influenced by Mars dynamics-delete], Mars atmosphere mean density characteristics (e.g. scale height) and density perturbations. **An Earth test would be valuable but not sufficient**	Because this is a cornerstone, this must be done early. **If aerocapture fails, the architectural ramifications are large**.	The technologies required for aerocapture using a Viking-shape aeroshell to a low Mars orbit are all at TRL=5 or higher. The recommendation would be to fly this proven shape and demonstrate aerocapture, and later fly the correct aeroshell shape. It is recommended that aerocapture be flown early (demonstration of technique for inclusion in architecture), mid (include the human-class shapes and constraints), and late (included as part of more full-up demonstrations)

Code

Priority	Where	When
VH = very high	ES = Earth surface	E = Early
H = high	EO = Earth orbit	M = Mid
M = medium	MN = Moon	L = Late
L = low	MR = Mars	A = Anytime

Very High Priority Items That Do Not Require Mars Testbed

Technology	Where	When
Bio-Isolation Systems	Moon	Early/Mid
Planetary Protection	Earth Surface	Mid
Connector Durability	Earth Surf	Mid

EXAMPLE OF VENUE CHOICE

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **1A. Conduct a Series of Three Aerocapture Flight Demonstrations [A]:**
  - 70 Deg. Sphere Cone Shape (robotic scale) to Demonstrate Aerocapture at Mars (Early).
  - New Entry Vehicle Configuration Suitable for Human Exploration (robotic scale), Aerocapture at Mars (Mid).
  - New Entry Vehicle Configuration Suitable for Human Exploration (Larger Scale, End-to-End Mission Sequence), Aerocapture at Mars (Late)
  - **Rationale: Aerocapture is the Most “Effective” Means for Decelerating at Mars:**
    1. Chemical Propulsion - Massive Propellant
    2. Direct Entry - Unacceptable “g”s for Humans; Landing Commitment From the Get-Go
    3. Aerobraking – Lengthy (Unacceptable?) Time Commitment
    4. Aerocapture – Mitigates Much of the Above Down-Side

    - Demands Precision Entry and Attitude Control & Knowledge of Mars Atmosphere Characteristics - See IVA Measurements Goals

Aerocapture May Be Mission Enabling

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **1B. Conduct a Series of Three In-Situ Resource Utilization Technology Demonstrations [S]:**

  1. ISRU Atmospheric Processing (Early)
  2. ISRU Regolith-Water Processing (Early)
  3. ISRU Human-Scale Application Dress Rehearsal (Late)

  - **Rationale**
    - Reduce Mission Cost & Design Envelope
    - Validate Earth-based Development & Testing
    - Utilize Flight Demonstrations to Increase Confidence in ISRU
    - Engage & Excite the Public
  - **Sequence**
    - Progress from “Certain” Resource (Atmosphere) to Scattered (Hydrated Minerals, Regolith Ice) to Uncertain x, y, z Distribution (Subsurface Water)
  - See IVA Measurements Goals for Water-Related Items

ISRU May Be Mission Enabling

Risks & Impacts Associated with ISRU

Risk	Impact
- Potential resource is not known with enough confidence to include in mission planning	- Loss of opportunity to minimize mission mass, cost, and/or risk
- Resource of minimum planned (required) accessibility, quality, and quantity is not present at landing site	Processing failure or reduced production rate: may lead to loss of mission if processing is critical
> Accessibility is insufficient (e.g. depth, distance, produceability, mineability)	
> Resource quality is insufficient (e.g. concentration, mineralogy, impurities, state, T, etc.)	
> Resource quantity is insufficient	
- Processing system is vulnerable to martian environmental effects (dust, thermal gradient, conductivity, albedo, , chemical effects, etc.)	- Processing failure or reduced production rate: may lead to loss of mission if processing is critical

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **1C. Demonstrate an End-to-End System for Soft, Pinpoint Mars Landing (10m to 100m accuracy) Using Systems Characteristics Representative of Mars Human Exploration Systems [A]. (Mid)**
  - **Rationale:**
    - **Safety and risk mitigation:** Landing near prepositioned supplies and emergency abort systems increases the likelihood of successfully accessing such in an emergency and enhances mission efficiency in non-emergency situations.
    - **Science accomplishment:** a site selected for human exploration may be selected because there is a specific science objective to be accomplished. Such could be sufficiently localized that landing in close proximity increases the probability of successful science accomplishment.
- Mars Robotic Science Program May Independently Develop Pin-Point Landing Systems

Goals 1A, 1B and 1C Testbed Sequencing Summary

Technology	Related Precursors	Early Testbed [2011 – 2016]	Mid Testbed [2018 – 2022]	Late Testbed [2024 – 2028]
Aerocapture Goal 1A	**Atmospheric characterization (Early)** **Entry system instrumentation (All the time)**	**70-deg sphere cone demo (to possibly include subsequent EDL)**	**New shape demo (to possibly include EDL)**	**New shape end-to-end mission demo**
ISRU Goal 1B	**Find and characterize accessible water (Early)**	**Atmospheric processing; regolith-water processing**		**Human-scale dress rehearsal w/ascent**
Pinpoint Landing Goal 1C	**Landing site characterization (Anytime)** **Atmospheric characterization (Early)** **Entry system instrumentation (All the time)**		**End-to-end system demo with human representative system characteristics**	

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **2A. Emplace Continuous, Redundant In-Situ Communications/Navigation Infrastructure. [S] (Late)**

  Rationale: Mission Safety and Effectiveness will Require the Development of High Band-Width Continuous and Redundant Communications.
- Mars Telecom Orbiter is a Related Precursor

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **2B. Investigate Long-Term Materials Degradation over times Comparable to Human Mission Needs. [S] (Mid)**

  Rationale: Our Current State of Knowledge of the Mars Environment is Not Sufficient to Enable Confident Design of Essential Mars Surface Space Systems. These include EVA Suits, Habitats and Ancillary Systems, Including Mobility. It is Essential to Verify the Capability of Materials to Tolerate Long Term Exposure (years) to Mars Environmental Phenomena. These include: Radiation; Temperature Extremes and Cycles; Wind; Atmosphere Chemical and Electromagnetic Properties; Soil and Dust Chemical, Mechanical, and Electromagnetic Properties; and Mars biology (if any).

MHP SSG Goal IVB – Technology Demonstration, Infrastructure Emplacement Priorities

- **3. Develop and Demonstrate Accurate, Robust and Autonomous Mars Approach Navigation. [T] (Mid)**

  Rationale: This is a Mission Safety Item. It Would Provide a Backup/Replacement to DSN-based Terminal Navigation for a Mission Time-Critical Event Such As Mars Orbit Insertion or Aerocapture.

General Observations

- Most Transit Sub-Team Items Do Not Need Demonstrations In Transit to Mars
- The Atmospheric Sub-Team Concentrated Primarily on Identifying System Level Technologies that Must be Demonstrated at Mars. Many Component-Level Items Exist
- Many Surface Sub-Team Items Were Transferred or Incorporated Into the Measurements (IVA)
- Short Stay versus Long Stay at Mars
  - Goals 1A, 1C, 2A and 3 are Independent of Stay Time
  - Goal 2B , Materials Degradation, Mosly Important for Long Stay
  - Goal 1B, ISRU, Mostly Applies to Long Stay Missions (Short Stay Could be a Useful “Assessment” Opportunity)
- Robotic Science Missions Can Contribute to Goal IVB
  - Pinpoint Landing Development
  - Mars Orbit Automated Rendezvous and Docking

TI Sub-Group Recommended Studies

- The TI Sub-Group Sees a Need for Systems-Level Studies
  - Optimal Configuration for Human Aeroassist Landing Vehicle
  - ISRU Trade Space

GOAL IVB Rewrite Summary - 1

	MEPAG 2001		MEPAG 2005
2 3	Demonstrate mid-range lift-to-drag (mid-L/D) aeroentry/aerocapture vehicle flight. Demonstrate high-Mach deployable aerodecelerator performance	1A	Conduct a Series of Three Aerocapture Flight Demonstrations: 1. 70 Degree Sphere Cone Shape (Robotic Scale) to Demonstrate Aerocapture at Mars (Earlly) 2. New Entry Vehicle Configuration Suitable for Human Exploration (robotic scale), Aerocapture at Mars (Mid). 3. New Entry Vehicle Configuration Suitable for Human Exploration (Larger Scale, End-to-End Mission Sequence), Aerocapture at Mars (Late)
4 5	Demonstrate In-Situ Propellant Production and In-Situ Consumables Production & Demonstrate In-Situ Water Collection and Conditioning Using Surface Resources.	1B	Conduct a Series of Three In-Situ Resource Utilization Technology Demonstrations: 1. ISRU Atmospheric Processing (Early) 2. ISRU Regolith-Water Processing (Early) 3. ISRU Human-Scale Application Dress Rehearsal (Late)

GOAL IVB Rewrite Summary - 2

	MEPAG 2001		MEPAG 2005
1	Demonstrate terminal phase hazard avoidance and precision landing	1C	Demonstrate an End-to-End System for Soft, Pinpoint Mars Landing (10m to 100m accuracy)
6	Demonstrate access to subsurface resources (See IVA, Measurements, Report)	2A	Emplace Continuous, Redundant In-Situ Communications/Navigation Infrastructure
7	Demonstrate plant growth in the Martian environment (Considered to be Low Priority by TI Sub-Group)	2B	Investigate Long-Term Material Degradation Over Times Comparable to Human Mission Needs
		3	Develop and Demonstrate Accurate, Robust and Autonomous Mars Approach Navigation